

# **CORRUGATED INTERNAL FUEL RAIL DAMPER**

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## ***Background Of the Invention***

[0001] In fuel rails for injector-based fuel injection systems, various devices associated with the fuel system cause pressure waves in the fuel to propagate through the fuel rails. Such pressure waves, if occurring at the wrong time, may cause a reduction in the fuel being injected into the engine when the injector is pulsed open causing a lean shift condition. In certain instances, the fuel injector may have a small amount of fuel leaving the fuel rail and being injected into the engine at the time the injector is pulsed open causing a rich shift condition. In addition, such pressure waves cause noise in the system that may be objectionable. Pressure pulses will give false readings to fuel pressure regulators by operating the regulator with a false indication of fuel pressure, which may result in fuel being bypassed and returned to the fuel tank.

[0002] A known pressure dampening system uses elastic walls forming the fuel supply line. As pressure pulses occur, the elastic walls function to dampen the pressure pulsations. Other pressure dampening systems use a pressure damper plugged in the end of a fuel rail with a pressure regulator at the other end. Still other pressure dampening systems use a compliant member operable to reduce peak pressure during injector firing events. The member is positioned in the fuel rail so as to not adversely affect the flow of fuel to an injector opening in the rail. The member is not free to rotate in the rail and the pressure pulses are dampened by the member, which is a pair of welded together shell halves with an enclosed airspace. Other pressure dampening systems use an in-line fuel pressure damper from the outlet of the fuel filter to the fuel rail. The damper is a pressure accumulator which operative to reduce transient pressure fluctuations induced by the fuel pump and the opening and closing of the fuel injectors.

[0003] Another dampening system utilizes an integral pressure damper that is attached to the fuel rail. The return tube is brazed to the rail and then at a convenient time in the assembly

process the damper, which is a diaphragm, is attached to the return tube and crimped into position. The diaphragm operates to reduce audible operating noise produced by the injector pressure pulsations.

[0004] Still another dampening system uses a pulse damper in the fuel pump comprising a hollow body formed of a thin walled tube of flexible and resilient plastic material with heat sealed ends forming at least one chamber. The chamber carries a compressible gas to dampen pressure pulsations. Another dampening system uses a bellows modulator inside a gear rotor fuel pump for reducing pump noise by reducing the amplitude of fuel pressure pulses. Yet another system uses a bellows-like device at the junction of the lines of the flow path of the fluid from a fuel feed pump thereby forming a discontinuity in the flow path to reduce compressional vibrations of fuel being conveyed.

### ***Summary of the Invention***

[0005] Briefly, the present invention provides a fuel rail assembly. The fuel rail assembly comprises a fuel rail having a longitudinal rail axis extending therethrough, the fuel rail having a fuel rail volume capable of receiving fuel; and a fuel damper element disposed within the fuel rail. The fuel damper element has a longitudinal damper element axis generally parallel to the longitudinal rail axis, the fuel damper element having a first portion and a second portion, the first portion with a continuous surface having a series of undulations, and the second portion having a smooth surface.

[0006] The present invention also provides for a damper element usable in a fuel rail. The damper element comprises an elongated member having a longitudinal damper element axis generally parallel to the longitudinal rail axis, the damper element having a first portion and a second portion, the first portion with a continuous surface having a series of undulations, and the second portion having a smooth surface.

[0007] The present invention provides a method of damping pressure pulsation in a fuel system having at least one fuel injector coupled to a pressurized fuel source with a fuel rail. In one preferred embodiment of the invention, the method is achieved by providing a fuel rail having a

predetermined internal volume; changing the predetermined internal volume of the fuel rail with placement of at least one damper element having a first portion and a second portion, the first portion with a continuous surface having a series of undulations, and the second portion having a smooth surface

### ***Brief Descriptions of the Drawings***

[0008] The accompanying drawings, which are incorporated herein and constitute part of this specification, illustrate an embodiment of the invention, and, together with the general description given above and the detailed description given below, serve to explain the features of the invention.

[0009] Figure 1 is an illustration of the fuel system according to a preferred embodiment.

[0010] Figure 2 is an illustration of a preferred embodiment of the damper element in its initial configuration prior to any changes in its configuration.

[0011] Figure 3A is an illustration of the damper element of Figure 2 in a second configuration.

[0012] Figure 3B is a cross-sectional view of Figure 3.

[0013] Figure 4A is an illustration of another embodiment of the damper element.

[0014] Figure 4B is a cross-sectional view of the damper element shown in Figure 4A.

[0015] Figures 5A, 5B, 5C, and 5D illustrate various curved surfaces that approximate various trigonometric functions for the preferred embodiment.

### ***Detailed Description of the Preferred Embodiments***

[0016] Referring to Figures 1-5, there is shown a fuel rail assembly 100 according to a preferred embodiment that can be coupled to a pressurized fuel source (not shown) and at least one fuel injector 10. The fuel rail assembly 100 includes a fuel rail 20 having a longitudinal rail axis A-A extending therethrough, the fuel rail 20 having an interior surface 22 defined by a rail wall 24. The interior surface 22 defines a fuel rail volume capable of receiving fuel that can be supplied by a pressurized fuel supply. Disposed within the fuel rail 20 is a fuel damper, i.e. a damper element 30. The damper element 30 operates to absorb fuel pressure fluctuations within

the fuel system. The damper element 30 has an interior volume and an exterior surface 32 defined by a wall surface, as seen in a cross-section view of Figure 3A. The damper element 30 includes a longitudinal damper element axis B-B that is generally parallel to the longitudinal rail axis. Alternatively, the two longitudinal axes can be oblique to each other.

[0017] The wall surface of the damper element 30 includes a first portion 34 and a second portion 36. Preferably, the second portion 36 includes a smooth surface. As used here the term smooth surface includes surfaces that have irregularities on its planar or curved surface but which irregularities can be quantified as a surface roughness  $R_a$  of no greater than 320 micrometer. Preferably, the first portion 34 has undulations or a corrugated surface formed thereon that is located on the first portion 34 by a virtual plane containing at least three points "A", "B" and "C" between a first end contiguous to an exterior surface 32 of damper element 30 and a second end contiguous to the exterior surface 32 of the first portion 34 such that a continuous surface, preferably a single continuous surface, must intersect the virtual plane at a plurality of locations between the first end and the second end. It should be noted here that the three points can be any arbitrary point as long as the three arbitrary points define a virtual plane that is intersected by a continuous surface at three or more positions. Preferably, the continuous surface comprises stacked surfaces that are oblique to the virtual plane so as to form a corrugated surface across the virtual plane. The stacked surfaces can be, for example, a sawtooth pattern or a series of rounded tooth pattern. Alternatively, the corrugated surfaces include a continuous surface that forms a plurality of planar surfaces (38a, 38b, 38c and so on) that are oblique to the virtual plane. It should be noted that the plurality of planar surfaces include a series of planar surfaces adjacent to one another such that every planar surface (38a) is parallel to every other planar surface (38c) in the series of planar surfaces.

[0018] In one preferred embodiment, the second portion 36 of the fuel damper element 30 includes a surface with a constant radius of curvature with respect to the axis of the damper element 30 or to any axis, shown here in Figure 3A. Preferably, the first and second portion 36s are formed from a single continuous surface of a suitable elongated member 30', as shown in Figure 2, that can be formed by stamping or rolling of the elongated member. It should be noted

here that a suitable elongated member can have a cross-section that is circular, square, rectangular, triangular or other polygons. Preferably, the cross-section of the elongated member in its initial configuration 30' is circular.

[0019] The stamping or rolling of the elongated member should be performed so as to generate an elongate member 30 having a first portion 34 with the corrugated surface while leaving the remainder of the second portion in, preferably, the same shape as prior to the forming operation that defines the first portion 36. Alternatively, the first portion 34 can be formed separately and then coupled to the second portion 36 by a suitable fastening technique, such as, for example, crimping, epoxy, gluing, brazing, bonding, welding and preferably laser welding. It should be understood that any suitable coupling technique could be employed such as, for example, a fastener as in a rivets or a bolt and nuts configuration. It should be recognized that an internal volume of the elongated member of Figure 2, in the initial configuration, could be changed to a different second internal volume subsequent to the forming operation. Preferably the second internal volume can be configured such that the internal volume of the initial configuration is greater than the second internal volume.

[0020] Depending on the operating conditions that the damper element 30 is subjected to, the flexibility of the damper element 30 is a function of the wall thickness of the elongated member and the percentage of the surface area of the elongated member that is corrugated. Preferably, the elongated member is a tubular member having a diameter of about 7 millimeter with thickness of the elongated member is about 0.3 millimeter such that when the tubular member is configured into the damper element 30, the corrugated surface area of the damper is approximately 25% to 50% of the exterior surface area of the elongated member. It should be noted that other thickness, diameter and ratios can be varied depending on operating conditions or other requirements.

[0021] The first and second portion together define an outer surface and an inner surface, the inner surface enclosing a predetermined internal volume that is sealed from the exterior of the damper element 30 and therefore is occluded from any contact with fuel when the damper element 30 is mounted within the fuel rail 20. The predetermined internal volume can be used to

determine the amount of damping required for the pressure pulsation within the fuel rail 20. The pressure pulsations can be damped by a combination of a spring constant of the corrugated surface, the elasticity of the second portion 36 or a suitable gas, for example, air, argon or nitrogen, that is hermetically sealed within the predetermined volume of the damper element. The damper element 30 can be hermetically sealed by a suitable fastening technique, such as, for example, crimping, epoxy, gluing, brazing, bonding, welding and preferably laser welding of the elongated member. It should be understood that any suitable coupling technique could be employed such as, for example, a fastener as in a rivets or a bolt and nuts configuration.

[0022] Referring to Figures 4A and 4B, another preferred embodiment is shown in which a cross-section of the second portion 36 is coupled to a first portion 34 to define a close-ended two-dimensional shape of at least three sides that touch only at their end points. The two dimensional cross-section can be of any polygons, including a rectangular polygon 361 as shown in Figure 4A. Here, the second portion 36 includes at least three planar surfaces 361a, 361b, 361c (Fig. 4B) that are coupled to the first portion 34 so as to define a predetermined volume of the damper element 30. The corrugated surface 381, preferably, includes a single surface having a series of planar surfaces 381a, 381b, 381c and so on extending across a virtual plane (dashed line). Alternatively, the corrugated surfaces can include various surfaces having other cross-sections as described above with respect to Figures 3A and 3B.

[0023] Referring to Figures 5A-5C, the continuous surface that forms the first portion 34 can have cross-sectional shapes that approximate various trigonometric functions. For example, in Fig. 5A, one cross-sectional shape of the first portion 34 can approximate the function  $y = \frac{1}{2} \cos x$  where  $y$  is the amplitude and  $x$  is any real number. In another example, the cross-sectional shape can approximate the function  $y = \cos 3x$ , as shown here in Fig. 5B. In a third example, the cross-sectional shape can approximate  $y = 2 \cos \frac{1}{3} x$ , as shown here in Fig. 5C. In a fourth example, the cross-sectional shape can approximate  $y = -2 \cos x$ . Other examples using other functions, such as, for example, a sine function, can be used depending on the number of corrugations, flexibility or operating characteristics as required. It should be recognized by those

skilled in the art that the shape of the surface can be varied depending on the application of the damper.

[0024] The method of damping pressure pulsations in a fuel injection system includes providing a fuel rail 20 having a predetermined internal volume, and changing the predetermined internal volume of the fuel rail 20 with placement of at least one damper element 30 with preselected damping characteristics. The damper element 30 includes a first portion 34 and a second portion 36, the first portion 34 with a continuous surface having a series of undulations, and the second portion 36 having a smooth surface. The fuel injection system used with the method has a pressurized fuel source (not shown) coupled to at least one fuel injector 10 with a fuel rail 20 establishing fluid communication between the pressurized fuel source and the at least one fuel injector 10.

[0025] With reference to Figures 2 and 4, a damper can be formed from a single member in a first configuration to a second configuration. The first configuration can be an elongated member that is changed to the second configuration such that the second configuration can include a first portion 34 and a second portion 36. The first portion 34 has a corrugated surface formed thereon that is located on the first portion 34 by defining a virtual plane containing at least three points "A", "B" and "C" between a first end contiguous to an exterior surface 32 of damper element 30 and a second end contiguous to the exterior surface 32 of the first portion 34 such that a continuous surface, preferably a single continuous surface, must intersect the virtual plane at more than two locations. In other words, the second configuration includes a member having at least one of rectilinear or a curvilinear surface that is contiguous to a planar member whose surface is corrugated.

[0026] The method also requires that the internal volume of the damper element 30 be sealed or occluded from communication with an exterior of the damper element 30 by a suitable fastening technique, such as, for example, crimping, epoxy, gluing, brazing, bonding, welding and preferably laser welding. It should be understood that any suitable coupling technique could be employed such as, for example, a fastener as in a rivets or a bolt and nuts configuration. It should be noted that the changing of the internal volume of the fuel rail 20 of the method

includes changing a first internal volume of the initial configuration of the damper element 30 to a second internal volume of the second configuration of the damper element 30. Reduction of pressure pulsation can be optimized by iteratively measuring the pressure pulses in the fuel rail 20 with different damper elements 30, each damper element 30 having a different internal volume or a different cross-sectional shape until a desired level of damping is achieved.

[0027] While the present invention has been disclosed with reference to certain embodiments, numerous modifications, alterations and changes to the described embodiments are possible without departing from the sphere and scope of the present invention, as defined in the appended claims. Accordingly, it is intended that the present invention not be limited to the described embodiments, but that it has the full scope defined by the language of the following claims, and equivalents thereof.